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ABSTRACT

Environmental effects have long been accepted as having an impact both on the tactical use of naval warfare platforms and on the naval warfare decision making process. Increased use of modeling and simulations (M&S) for training and analysis requires better understanding of the unique attributes of meteorological and oceanographic (METOC) data and its application in M&S. The well-developed field of forecasting METOC variation over time can be leveraged to better optimize METOC data flow into naval warfare simulations (NWS) through the application of information entropy techniques. The SAFECUR magnetic mine sweeping tactical decision aid (TDA), is evaluated for sensitivity to METOC variation. Incompatibility of spatial and temporal scales and abstraction levels between METOC information and NWS applications is noted. Results of the studies indicate that many tactical effects of METOC variation may be transparent to command and control measures of effectiveness. Validation and verification of TDA's must include studies of sensitivity to full spectrum METOC variation. Averaging or linearly interpolating values over unknown regions is unwise given observed METOC data's non-linear characteristics.

1. INTRODUCTION

SAFECUR is a computer program that calculates safe current for magnetic minesweeping with closed-loop sweeps or electrode sweeps. It was developed by the Coastal Sea Systems Command for Commander Mine Warfare Command. SAFECUR provides a simpler, faster, and more accurate means of calculating safe current values than the NWP 27-1-1 procedures upon which it is based (Jones, 1992b). The safe current value is the highest level of current that can be used in a magnetic sweep without having mines fire ahead of or inside the damage radius of the given mine countermeasures vehicle (MCMV). The safe current value for electrode sweeps is a function of the vehicle-sweep configuration, type of mines employed, the sweep speed used, the assumed damage radius, and the environment. Inputs to the SAFECUR program take place through menus as listed in Figure 1. The meteorological and oceanographic (METOC) inputs for the electrode sweep are based on a two layer model as illustrated in Figure 2. The two layer model assumes that two horizontal conducting mediums with conductivities C1 and C2 exist. The depth of the first conducting layer from the surface downward is defined as the electrical depth (ED). The actual depth (AD) is the depth from the surface to the sea floor. ED/AD is the ratio of these two depths. The reflection coefficient

$$Q = (C1-C2\}/\{C1+C2)$$

is a function of the conductivities. Q and ED/AD must be determined experimentally through ocean surveys. This information is typically classified and comes from the Naval Oceanographic Office (NAVO) as "MACAS" data.

The SAFECUR program description, manuals, and several of its algorithms are currently classified "confidential". Many of the values used in this paper have been normalized or abstracted to maintain the unclassified nature of the paper. Unless otherwise noted, the fixed parameter values are those used for software verification as listed in Appendix A of Jones (1992b).

2. EXPERIMENT DESIGN

Two sets of data were evaluated using the SAFECUR code. Our goal was to test the sensitivity of SAFECUR to METOC variations using these two data sets. First, the maximum safe current was calculated for Actual Depth (AD) values of from 10 to 200 feet in one foot increments while varying the Electrical Depth/Actual Depth (ED/AD) ratio values from 0.04 to 3.04 in increments of 0.01. Second, maximum safe current values were calculated from a set of observed MACAS data provided by NAVO. Evaluating the first data set required modifying the original SAFECUR code by inserting two, nested FORTRAN "do-loops" between the input menu routines and the subroutine calls that calculate the actual safe current values. The "do-loops" incremented the AD and ED/AD values as described above. The maximum safe current values calculated were written to a MATLAB readable file for analysis and visualization. The MACAS data provided by NAVO was loaded into a MATLAB session on a classified PC in the Secure Computing Laboratory at the Naval Postgraduate School.

The MACAS data was "groomed" to remove erroneous data and modified to permit unclassified presentation of the results. A 71 data point subset of the MACAS data set was chosen for analysis. This data subset, whose geographic distribution is displayed in Figure 3, possesses a reasonably uniform spatial distribution over a 0.2 by 0.2 degree area. The 71 points were read into the SAFECUR code with single "do-loop", safe current values were calculated, and the values output to a MATLAB readable file for visualization and analysis. The MATLAB "MESHGRID" routine was used to take the irregularly spaced MACAS data points and construct a mesh plot of the maximum current values.

3. METOC IMPACT ON SAFECUR SIMULATIONS

The SAFECUR software generated two sets of maximum safe current values. The first experiment generated a set of maximum safe current values for water depths between 10 and 200 feet and for ED/AD values from 0.04 to 3.04. Front and rear views of the maximum horizontal safe current surface created by these values are plotted in Figures 4 and 5. Between 50 and 200 feet of depth the maximum safe current values are nearly constant for a fixed ED/AD ratio, but the maximum safe current values vary in a strongly non-linear manner as a function of ED/AD for a fixed water depth. With the exception of a small region near the 50 foot depth value, maximum safe current is a relatively constant function of depth for a given ED/AD value. For a fixed depth the maximum safe current varies in a strongly non-linear manner with variation in ED/AD value. The N=71 subset of MACAS data generated the maximum horizontal safe current value surface (Figure 6) as a function of the location of the MACAS data. The MESHGRID routine interpolates irregularly spaced data for plotting as a surface over a regularly spaced grid.

An important concern for the operational employment of the SAFECUR software as a magnetic mine sweeping TDA is to avoid sweeping in a region where a high value of current is present in a region of highly variable maximum safe current values. As an example consider the region on the surface in Figure 6 at 0.1 north-south and 0.01 east-west. If a maximum safe current value is determined using the MACAS data point at this location, then no matter in which direction the mine sweeping platform moves it will find itself in a region where it exceeds its maximum safe current. Based on the available data, which is sparse considering the amount of METOC variation, at least five of these maximum safe current "relative maxima" appear to exist in Figure 6. The region on the surface at 0.1 North-South and 0.01 East-West is hazardous. A maximum safe current value determined at this point will exceed the maximum safe current for sweeping in all nearby areas. No matter in which direction the mine sweeping platform moves it will find itself in a region where it is exceeding its maximum safe current.

4. CONCLUSIONS

The sensitivity of the SAFECUR TDA to variability in input data exceeds the resolution of the MACAS data collected by NAVO. This is a heads up both for the data collection authorities at NAVO and the TDA developers throughout the military research establishment. METOC data collected through surveys designed to support a warfare community effort must have a resolution commensurate with both the degree of natural variability and the effect this variability has on the safe and successful conduct of the operations being supported. The guidance provided with the SAFECUR TDA gave no indication of the potential hazards involved in using the TDA over regions of varying conditions. While the user could be reasonably expected to calculate maximum safe current values at several locations in their area of interest, the variation between adjacent MACAS survey points is large and no guidance on interpolating between such points is available. Does METOC variability such as this concern other TDAs and to what extent can changes in verification and validation procedures identify them? The study of environmental effects on naval warfare simulations as a subject area is exceedingly broad in scope. Operations analysts can concentrate their expertise and apply their detailed knowledge about a single simulation to a myriad of problems. The METOC professional must become a near expert on every simulation they use if they are to effectively employ METOC in them. METOC variable values and their variation possess attributes that uniquely effect both the physics and the psyche (soft factors) of naval warfare. The cumulative effects of environmental variation on command and control processes is significantly different enough from the individual tactical problems to warrant an independent field of study. As some of the Navy's preeminent users of forecasting techniques, METOC professionals should help to further exploit this relationship.

MENU 1: MCMV WITH SWEEP

Sweep	From Sweep List Submenu to Menu 1
UDmgDist	Unit of Damage Distance (1=yd, 2=m)
DmgDist	MCMV's horizontal Damage Distance
MaxSpeed	Maximum speed (kts)
MaxRatCur	Maximum rated current (kA)
MaxGenVol	Maximum generator voltage (V)
MaxGenPow	Maximum generator power (Kw)

SWEEP LIST SUBMENU TO MENU 1

Swpid	#	Sweep	Configuration	Description
	1	M Mk 4(m)	A	Two-boat closed-loop
	2	M Mk 5(a)	A	Straight-tail two-electrode (300-yd seperation)
	3	M Mk 5(a)	C	Straight-tail two-electrode (450-yd separation)
	4	M Mk 6(a)	A	Diverted one side, J, 2 electrodes
	5	M Mk 6(h)	A	Diverted one side, closed loop
	6	M Mk 6(q)	A	Small boat, diverted one side, closed loop
	7	M Mk 7(b)	A	Diverted two sides, 3 electrodes
	8	M Mk 7(b)	B	Diverted two sides, 3 electrodes
	9	M Mk 7(d)	A	Small boat, diverted two sides, closed loop
	10	M Mk 7(d)	B	Small boat, diverted two sides, closed loop

MENU 2: MCMV'S MEASURED MAGNETIC FIELD

UCodeDepth	Unit of CodeDepth (2=m, 3=ft)
CodeDepth	Depth corresponding to Hz_mcmv and Hz_gen
Uhz	Unit of Hz_mcmv and Hz_gen (1=nT, 2=mG, 3=gam)
Hz_mcmv	MCMV's constant field, z component
Hz_gen	Generator stray field per kA, z component

MENU 3: MINE'S CHARACTERISTICS

MineType	1=Ground, 2=Moored
FldComp	Magnetic field component (1=hor, 2=ver, 3=tot)
UHm	Unit of Hm (1=nT, 2=mG, 3=gam)
Hm	Threshold actuation level
Tm	Threshold stretch interval (sec)

MENU 4: ENVIRONMENT

Udepth	Unit of depth (2=m, 3=ft, 5=fm)
CaseDepth	Mine case depth
AD	Actual depth of the sea bottom
Q	Reflection coefficient
ED/AD	Electrical Depth/Actual Depth
UWatCon	Unit of WatCon (1=mmho/cm, 2=mho/m)
WatCon	Water conductivity (if unknown can be computed from Temperature and Salinity by the WatCon submenu)

Figure 1 Inputs and sweeps in the safe current program after Jones (1992a)

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$$Q = \frac{c_1 - c_2}{c_1 + c_2}$$

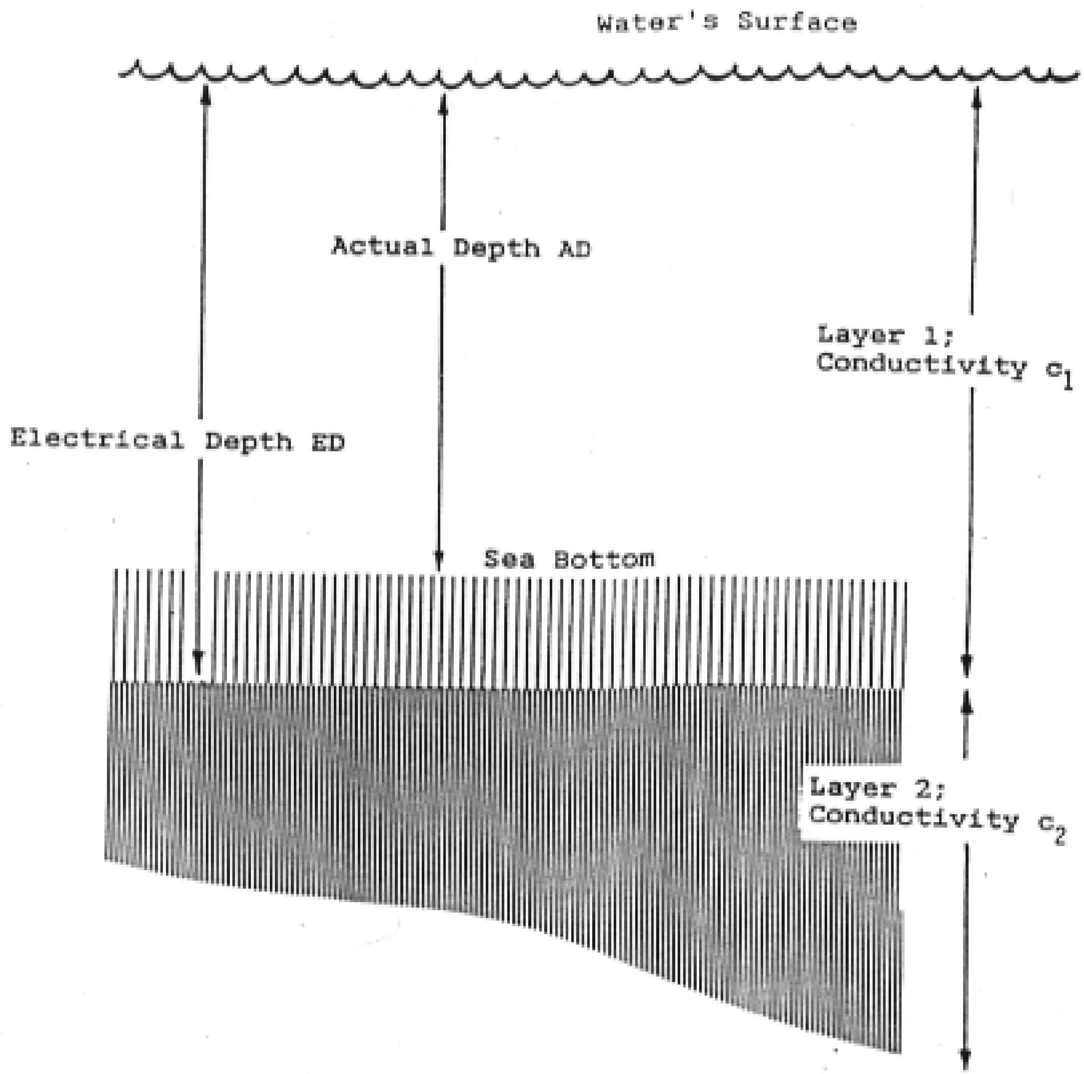

Figure 2. Two-Layer Model, from Jones (1992a).

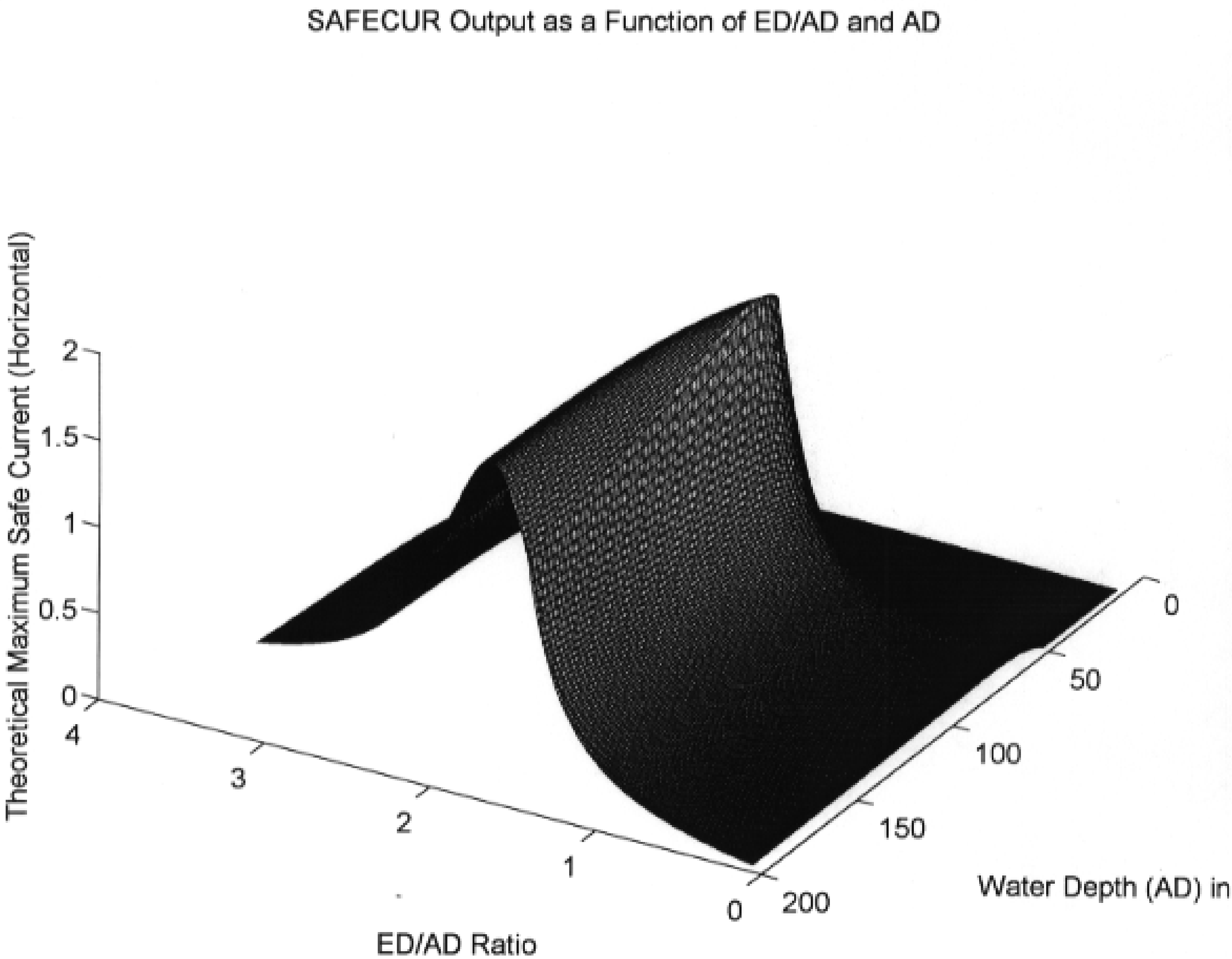

Figure 4. Front view of the Surface plot of Maximum Horizontal Safe Current as a function of ED/AD ratio and water depth. Between 50 and 200 feet of depth the maximum safe current values are nearly constant for a fixed ED/AD ratio, but the maximum safe current values vary in a strongly non-linear manner as a function of ED/AD for a fixed water depth.

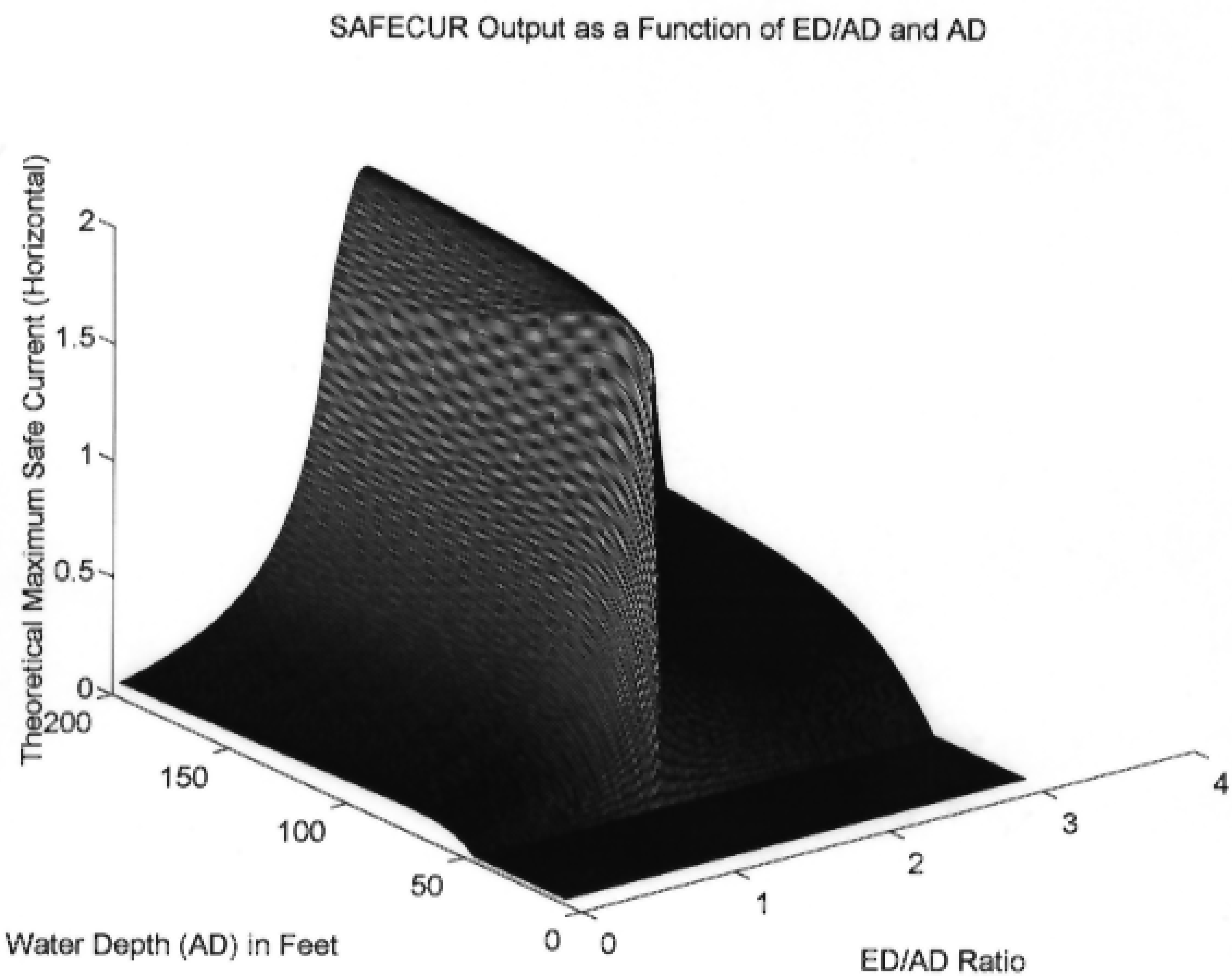

Figure 5. Rear view of the Surface plot of Maximum Horizontal Safe Current as a function of ED/AD ratio and water depth. Between 50 and 200 feet of depth the maximum safe current values are nearly constant for a fixed ED/AD ratio, but the maximum safe current values vary in a strongly non-linear manner as a function of ED/AD for a fixed water depth.

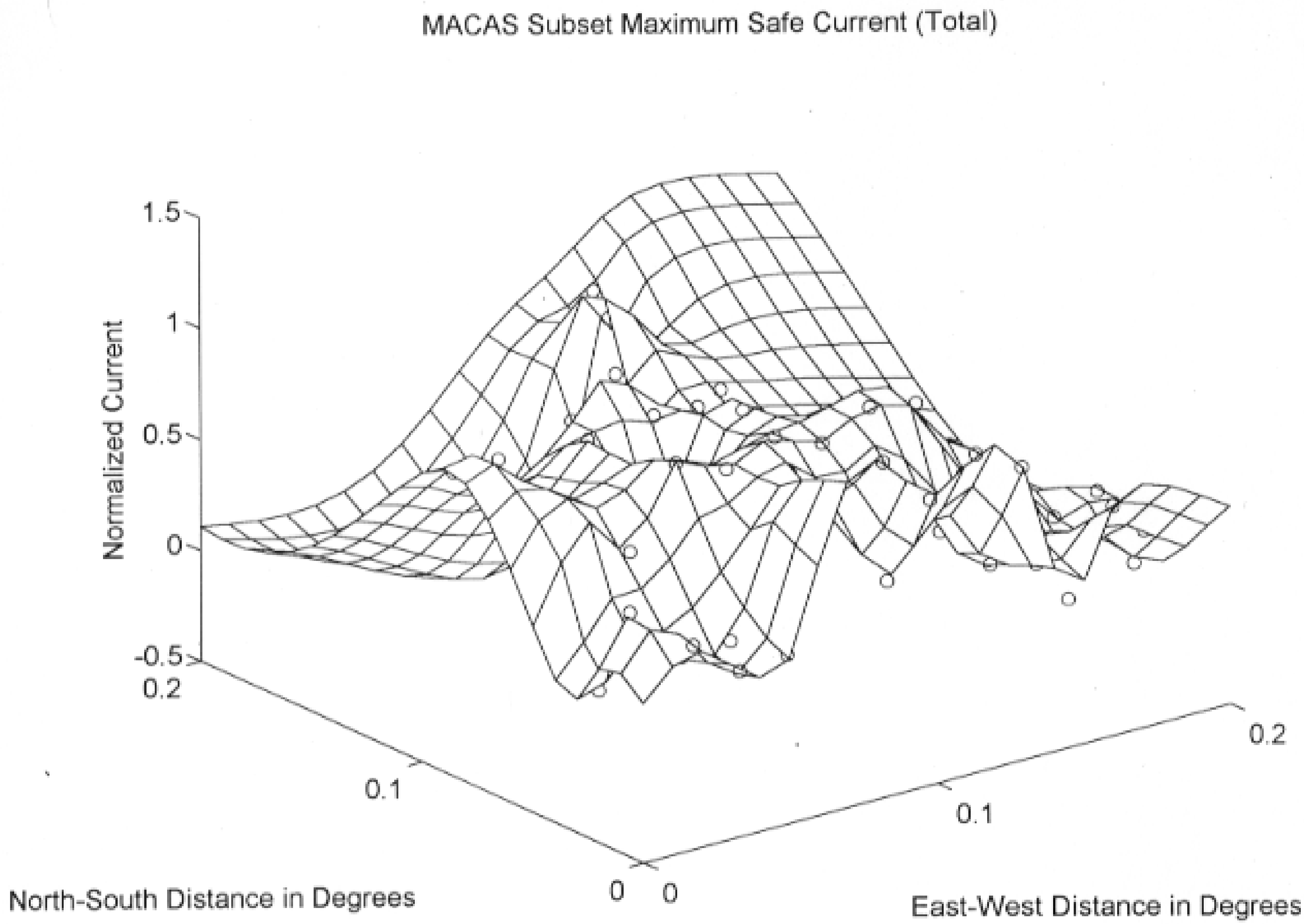

Figure 6. MESHGRID Surface plot of Maximum Horizontal Safe Current calculated for the N=71 data point subset of MACAS data. The region on the surface at 0.1 North-South and 0.01 East-West is hazardous. A maximum safe current value determined at this point will exceed the maximum safe current for sweeping in all nearby areas. No matter in which direction the mine sweeping platform moves it will find itself in a region where it is exceeding its maximum safe current.

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